

INVENTORS: Alberto DANIONI and Giulio RICOTTI

**DEVICE FOR DRIVING A POWER TRANSISTOR OF A VOLTAGE
CONVERTER PROVIDED WITH A PIEZOELECTRIC TRANSFORMER
5 AND CORRESPONDING VOLTAGE CONVERTER**

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims priority from prior Italian Patent
Application No. MI2002A002299, filed October 29, 2002, the entire disclosure of
10 which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to voltage converters, and more particularly to a
15 device for driving a power transistor of a voltage converter provided with a
piezoelectric transformer and a voltage converter including such a device.

2. Description of Related Art

Switching voltage regulators provided with power transistors driven suitably
20 by circuitry are generally known. In some cases the regulators include some
piezoelectric transformers adapted to convert the applied electrical energy by
exploiting a mechanical resonance.

The value of the output voltage in a piezoelectric transformer depends greatly
on the value of the frequency of the input signal; in fact the piezoelectric transformer
25 is adapted to transfer electrical energy only in a very narrow frequency band around its
mechanical resonance frequency. With respect to the typical electromagnetic
transformers, piezoelectric transformers present the advantages of having reduced
sizes and weights and a high efficiency (on the order of 90%). For this reason it is

EXPRESS MAIL LABEL NO. EV343426567US

used in different applications in which small size and high efficiency requirements are fundamental, as in the case of portable devices that are supplied from batteries.

Figure 1 shows the electrical circuit equivalent for a piezoelectric transformer in the case in which the input signal is at the mechanical resonance of the transformer.

5 A first series of components constituted by a capacitor C_{d1} and a resistor R_c is arranged in parallel to a second series of components constituted by a resistor R , an inductor L , a capacitor C , and a voltage generator V_{out}/N (where N is the transformer ratio and V_{out} is the output voltage). A current I_2 goes through the second series of components, and both the first series of components and the second series of
10 components are connected between an input voltage V_{in} and ground. The circuit also includes a current generator I_2/N and a capacitor C_{d2} connected in parallel to one another and connected between the output voltage V_{out} and ground. The capacitor C_{d1} generally has a high value and this causes the application of an input voltage V_{in} of the sinusoidal type for keeping the efficiency of the transformer high.

15 Normally a filtering inductor is placed upstream of the transformer in voltage converters that have piezoelectric transformers; the value of the inductor is selected according to the capacitor C_{d1} and the mechanical resonance frequency.

Figures 2 and 3 show two circuit configurations of a switching DC/DC converter. In Figure 2, an inductor L_1 filters a square wave signal derived from the
20 half bridge constituted by transistors M_1 and M_2 , which are connected in series between a voltage V_{in1} and ground and are driven by a driving device 5. The inductor L_1 is connected to the non-drivable terminal common to the transistors M_1 and M_2 and to a piezoelectric transformer 1 that has the electrical circuit equivalent shown in Figure 1. The output sinusoidal voltage signal of the piezoelectric
25 transformer 1 is rectified by a rectifier circuit 2 and is applied to a load $LOAD$. A part of the voltage V_o applied to the load, that is the voltage $R_2 \cdot V_o / (R_1 + R_2)$, is supplied to the inverting terminal of an error amplifier 3. The non-inverting terminal is connected to a reference voltage V_{ref} . The output signal of the error amplifier 3 is supplied to a voltage controlled oscillator (VCO) 4 that causes the switching
30 frequency to be sent to the driving device 5; the driving of the transistors M_1 and M_2

occurs with a duty cycle of 50%. The VCO 4 is normally set for operating in a frequency interval A that is monotone, fixed, and belongs to the transfer characteristic of the transformer, as shown in Figure 4. The frequency is changed according to the desired output voltage. When using the converter shown in Figure 2, the
5 determination of the resonance frequency of the transformer, which may change based on the resistive value of the load and based on the operating temperature, is difficult and therefore the suitable setting of the VCO 4 is difficult.

Figure 3 shows a DC/DC converter which differs from the circuit of Figure 2 by the presence of a single MOS power transistor M3 having its source terminal
10 connected to ground and its drain terminal connected to an inductor L2, which has in turn its other terminal connected to the input voltage V_{in1} . The driving device 6 drives the single transistor M3 with a duty cycle of 50%. In this circuit a quasi-sinusoidal signal is applied to the piezoelectric transformer 1 due to the resonance between the inductor L2 and the capacitor Cd1 of the transformer 1. The capacitor
15 Cd1 is discharged before the turning on of the transistor M3 and before the consequent recharging of the inductor L2. In such a circuit, the efficiency of the transformer is linked to the switching frequency.

SUMMARY OF THE INVENTION

20 In view of these drawbacks, it is an object of the present invention to provide a device for driving a power transistor of a voltage converter provided with a piezoelectric transformer that overcomes these drawbacks.

Another object of the present invention is to provide a voltage converter that includes such a device.

25 One embodiment of the present invention provides a driving device for driving at least one power transistor of a voltage converter that includes a piezoelectric transformer. The power transistor has a first non-drivable terminal coupled to an input voltage and to the input of the piezoelectric transformer. The converter includes an inductor coupled between the input voltage and the piezoelectric transformer, and a
30 resistor coupled between a second non-drivable terminal of the power transistor and

EXPRESS MAIL LABEL NO. EV343426567US

ground. The driving device is coupled to the drivable terminal of the power transistor, to the input of the piezoelectric transformer, and to the second non-drivable terminal of the power transistor so as to detect a first voltage value and a second current value. The driving device is adapted to cause the turning on of the power transistor if the first
5 voltage value is equal to a third prefixed voltage value, and to cause the turning off of the power transistor if the second current value is equal to a fourth prefixed current value.

Another embodiment of the present invention provides a switching voltage converter that includes a piezoelectric transformer, at least one power transistor, an
10 inductor, a driving device, and a resistor. The power transistor has a first non-drivable terminal coupled to an input voltage and to an input of the piezoelectric transformer. The inductor is coupled between the input voltage and the piezoelectric transformer, and the driving device is coupled to the drivable terminal of the at least one power transistor. The resistor is coupled between a second non-drivable terminal of the at
15 least one power transistor and ground. The driving device is also coupled to the input of the piezoelectric transformer and to the second non-drivable terminal of the at least one power transistor so as to detect a first voltage value and a second current value. The driving device is adapted to cause the turning on of the at least one power transistor if the first voltage value is equal to a third prefixed voltage value, and to
20 cause the turning off of the at least one power transistor if the second current value is equal to a fourth prefixed current value.

Other objects, features, and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and specific examples, while indicating preferred
25 embodiments of the present invention, are given by way of illustration only and various modifications may naturally be performed without deviating from the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

30 Figure 1 is an electrical circuit equivalent of a piezoelectric transformer;

EXPRESS MAIL LABEL NO. EV343426567US

Figure 2 shows a conventional switching DC/DC converter;

Figure 3 shows another conventional switching DC/DC converter;

Figure 4 shows the characteristic of the gain G as a function of the frequency f of a piezoelectric transformer;

5 Figure 5 shows a DC/DC converter that includes a driving device for driving a power transistor in accordance with a preferred embodiment of the present invention;

Figure 6 shows in detail one embodiment of a DC/DC converter according to the present invention; and

10 Figure 7 shows the driving signal of the power transistor and the waveform of the input voltage of the piezoelectric transformer in the converter of Figure 6.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described in detail hereinbelow with reference to the attached drawings.

15 Figure 5 shows a DC/DC converter that includes a driving device for driving a power transistor in accordance with a preferred embodiment of the present invention. The converter includes a MOS power transistor M that has its drain terminal coupled to an input voltage V_i and to the input of a piezoelectric transformer 10, which has the electrical circuit equivalent shown in Figure 1. The output voltage of the piezoelectric
20 transformer 10 is supplied to the rectifier circuit 12 and the rectified voltage V_{10} is applied to a load 13. The converter also includes an inductor L_{10} that is inserted in the electrical path between the input voltage V_i and the piezoelectric transformer 10. For example, it is inserted between the drain terminal of the transistor M and the input voltage V_i in the exemplary embodiment of Figure 5. The converter further includes a
25 driving device 11 which is coupled to the driving terminal of the power transistor M and which is adapted to cause the turning on and off thereof for prefixed time periods. The converter also includes a resistor R_s coupled between the source terminal of the transistor M and ground. During the turning on step of the transistor M , the input voltage of the transformer is low and is determined by the current flowing through the
30 inductor L_{10} and by the resistor R_s . In this step, the inductor L_{10} is charged by

EXPRESS MAIL LABEL NO. EV343426567US

energy. At the turning off of the transistor M, the energy of the inductor L10 is discharged on the capacitor Cd1 of the transformer 10 by producing the sinusoidal half wave that excites the transformer 10.

5 The driving device 11 is coupled to the input of the piezoelectric transformer 10 and to the source terminal of the power transistor M so as to detect a first voltage value V_t and a second current value. The driving device is adapted to cause the turning on and the turning off of the power transistor M if the first voltage value V_t is equal to a third prefixed voltage value and the second current value is equal to a fourth prefixed current value, respectively. The last value is set by the output signal of a
10 transconductance error amplifier 14 which receives at its inverting terminal a part of the voltage V_{10} applied to the load 13, that is the voltage $R_b \cdot V_{10} / (R_a + R_b)$. The non-inverting terminal is connected to a reference voltage V_{ref10} , for example of 820mV.

Figure 6 shows in detail one embodiment of a DC/DC converter according to
15 the present invention. As shown, the driving device 11 of this exemplary embodiment includes the comparators 20 and 21 and the logic circuit 23 for driving the transistor M. The comparator 20 has its inverting terminal coupled to the drain terminal of the transistor M and its non-inverting terminal connected to a reference voltage V_{th10} (for example of 820mV) that corresponds to the third voltage value. The inverting
20 terminal of the comparator 20 is preferably coupled to the drain terminal of the transistor M through a resistive divider made up of a resistor R_d arranged between the inverting terminal and ground and a resistor R_c arranged between the inverting terminal and the drain terminal of the transistor M. The comparator 21 has its inverting terminal connected to the output of the error amplifier 14 and its non-
25 inverting terminal connected to the source terminal of the transistor M. The comparator 20 sends a signal to the logic circuit 23 for turning on the transistor M when the voltage V_t at the drain terminal is equal to the voltage V_{th10} , while the comparator 21 sends a signal to the logic circuit 23 for turning off the transistor M when the value of the current at the source terminal, that is the current that goes

through the resistor R_s , is equal to the current value of the output signal of the error amplifier 14.

5 The driving device 11 preferably also includes another comparator 22 having its non-inverting terminal connected to the source terminal of the transistor M and its inverting terminal connected to a reference current I_{th10} , for example of 700mA. When the current in the resistor R_s is equal to the value of the current I_{th10} , the comparator 22 sends a signal to the logic circuit 23 for turning off the transistor M.

10 With the use of such a driving device 11, the value of the inductor L_{10} no longer depends on the value of the mechanical resonance of the transformer 10 and on the capacitor C_{d1} , but instead serves only to generate the sinusoidal arc adapted to excite the transformer 10.

Further, the switching frequency may be changed by changing the value of the resistor R_s , so as to extend or shorten the time period in which the inductor is charged. The maximum current value at the resistor R_s is set by the error amplifier in
15 dependence on the value of the output voltage V_{10} and the reference voltage V_{ref10} . If the output voltage increases the switching frequency decreases and therefore, with reference to Figure 4, the frequency interval to use for the transfer characteristic of the transformer is the interval B.

20 The presence of the driving device 11 allows the value of the inductor L_{10} to be unlinked from the transformer features, so as to allow a high efficiency for all of the frequency values.

In Figure 7, the waveform of the input signal V_t of the piezoelectric transformer 10 and the waveform of the driving signal S_G at the gate terminal of the MOS transistor M in the converter of Figure 6 are shown.

25 While there has been illustrated and described what are presently considered to be the preferred embodiments of the present invention, it will be understood by those skilled in the art that various other modifications may be made, and equivalents may be substituted, without departing from the true scope of the present invention. Additionally, many modifications may be made to adapt a particular situation to the
30 teachings of the present invention without departing from the central inventive

EXPRESS MAIL LABEL NO. EV343426567US

concept described herein. Furthermore, an embodiment of the present invention may not include all of the features described above. Therefore, it is intended that the present invention not be limited to the particular embodiments disclosed, but that the invention include all embodiments falling within the scope of the appended claims.

5